6-H
PREDESIGN INITIAL DILUTION ASSESSMENT

**FINAL
ENVIRONMENTAL
IMPACT STATEMENT**

**Brightwater
Regional Wastewater
Treatment System**

APPENDICES

Final

Appendix 6-H
Predesign Initial Dilution Assessment

August 2003

Prepared by King County

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EXECUTIVE SUMMARY

This report documents the predesign assessment of initial dilution at two potential diffusers for discharge of treated effluent from the proposed Brightwater Treatment Plant. The general approach was to compute the probability of occurrence of various levels of dilution under a wide range of discharge and ambient conditions, using mathematical formulas and scientific models. The UM3 and RSB/NRFIELD modules of EPA Visual Plumes Model were used to calculate initial dilutions and submergence, that occur when the plume reaches its trapping level. The dilution probabilities were determined from a 51-year simulation of flow, 4 ½ years of ambient density observations, and distributions of current speeds.

The analysis was performed for the entire range of effluent discharges, forty-two ambient stratification conditions, and five ambient current speeds in each of the two zones. In all, 48,720 cases were simulated. Initial dilutions are reported at the acute and chronic compliance distances, along with the plume submergence below the water surface at the near field mixing boundary (trapping depth).

Both outfall alternatives achieve a minimum initial dilution of 100:1 at the edge of an estimated zone for chronic compliance. The median dilutions at the edge chronic mixing zone ranged from 630:1 to 1548:1 under the various scenarios modeled. Minimum dilution at the zone for acute compliance ranged from 54:1 to 206:1. In general, lower acute dilutions were obtained under high effluent flow rates and high ambient current conditions. Larger dilutions were obtained under the lowest modeled flow, low ambient current conditions, and weak stratification.

1.0. INTRODUCTION

King County has prepared a Draft Environmental Impact Statement (Draft EIS) and Final Environmental Impact Statement (Final EIS) on the Brightwater Regional Wastewater Treatment System. The Final EIS is intended to provide decision-makers, regulatory agencies and the public with information regarding the probable significant adverse impacts of the Brightwater proposal and identify alternatives and reasonable mitigation measures.

King County Executive Ron Sims has identified a preferred alternative, which is outlined in the Final EIS. This preferred alternative is for public information only, and is not intended in any way to prejudge the County's final decision, which will be made following the issuance of the Final EIS with accompanying technical appendices, comments on the Draft EIS and responses from King County, and additional supporting information. After issuance of the Final EIS, the King County Executive will select final locations for a treatment plant, marine outfall and associated conveyances.

The County Executive authorized the preparation of a set of Technical Reports, in support of the Final EIS. These reports represent a substantial volume of additional investigation on the identified Brightwater alternatives, as appropriate, to identify probable significant adverse environmental impacts as required by the State Environmental Policy Act (SEPA). The collection of pertinent information and evaluation of impacts and mitigation measures on the Brightwater proposal is an ongoing process. The Final EIS incorporates this updated information and additional analysis of the probable significant adverse environmental impacts of the Brightwater alternatives, along with identification of reasonable mitigation measures. Additional evaluation will continue as part of meeting federal, state and local permitting requirements.

Thus, the readers of this Technical Report should take into account the preliminary nature of the data contained herein, as well as the fact that new information relating to Brightwater may become available as the permit process gets underway. It is released at this time as part of King County's commitment to share information with the public as it is being developed.

The Brightwater Draft EIS identified three alternatives for the project, consisting of two proposed treatment plant sites, three possible conveyance corridors and two outfall zones. A treatment plant at the Unocal site in Edmonds was linked to an outfall in Zone 6. The alternatives for a system with a treatment plant site at Route 9 incorporated two conveyance corridors to connect the plant with an outfall in Zone 7S. Additional investigations conducted since the Draft EIS was issued have provided additional detail and refinement to the outfall alignment and diffuser location. These investigations allow this report to provide more detailed information about the initial dilution from a proposed diffuser location in each zone.

1.1   Background

During the site selection process for the Brightwater system, initial dilution estimates were made at a number of the potential outfall locations. The siting process identified a number of areas in Puget Sound, called "zones", where the terminus of an ocean outfall or "diffuser," might be sited to discharge treated effluent from the proposed Brightwater Treatment Plant. In the Phase 2 evaluation (King County, 2001a), initial dilutions were assessed at 17 zones. In the Phase 3 assessment (King County, 2002a), the assessment was performed at Zone 6, Zone 7N and Zone 7S diffuser site B. In addition, dilutions were calculated at the edge of acute and chronic mixing zones, whose size was estimated based on the maximum size allowed by Ecology, which has been applied to King County's current treatment plant discharges. The Brightwater Draft EIS identified three system alternatives, each with a marine outfall in either Zone 6 (Unocal) or Zone 7S (Route 9). These zones continue to be referenced as Zone 6 and Zone 7S, consistent with the original labels given during the selection process, and are depicted in Figure 1.

Since the issuance of the Draft EIS, additional bathymetric surveys, geophysical investigations and further engineering design have been used to develop preferred outfall alignments in each zone. These alignments are presented in *Project Description: Marine Outfall* (King County, 2003a) and differ in detail from the conceptual alignments included with the Draft EIS, varying primarily in the location of the diffuser and pipeline route down the side slope of Puget Sound. Predesign work has also selected a preferred diffuser length of 500 feet, which is described more fully in *Diffuser Predesign* (King County, 2003b)

Initial dilution of an effluent discharged to a receiving water body depends on a number of factors. Marine outfalls usually terminate in multi-port diffuser structures, promoting rapid dilution of effluent with ambient marine waters. Upon discharge, the jet-like momentum of the effluent exiting the diffuser structure results in vigorous mixing with ambient seawater very near the diffuser port. The effluent's buoyancy then results in substantial additional mixing as it rises in the water column due to a difference in density. When the receiving water column is density stratified, sufficient dilution may occur at a certain depth so that the diluted effluent becomes denser than the overlying surface water and is subsequently trapped below the surface. The diluted effluent then forms a wastefield around this trapping depth, which is then spread and transported laterally by currents and eddies generated by wind, tides, estuarine transport mechanisms and bathymetric features.

1.2   Terminology

Because terminology associated with plume characteristics and initial dilution modeling may be subject to multiple interpretations or definitions, a description of some key terms in this report is provided below. Figure 2 shows a schematic illustration of terminology related to mixing zones and regions of initial dilution. The diffuser is a section of pipeline located at the terminus of the outfall containing openings (ports) spaced along its length from which the effluent is introduced into the ambient waters. The effluent typically leaves the diffuser with an initial momentum and positive buoyancy, resulting in rapid mixing with the ambient waters. The plume is the region containing the effluent as

it mixes, which rises in the water column until sufficient mixing and dilution have occurred, so that the plume no longer has any momentum or buoyancy of its own. The region in which this mixing occurs is the nearfield region, and the horizontal distance within which this mixing occurs is termed the Zone of Initial Dilution (ZID), or hydrodynamic mixing zone. After this mixing, the area where the plume is located is called the farfield region, where the plume is further advected and mixed by ambient currents and turbulence.

The areas where mixing occurs are important because water quality criteria are evaluated at the edge of the acute and chronic mixing zones. These acute and chronic mixing zones are specified by the Washington Department of Ecology in the Surface Water Quality Standards (WAC 173-201A). The chronic mixing zone is typically calculated by taking a horizontal distance from the diffuser of 200 feet plus the depth of the diffuser below MLLW. The acute mixing zone is 10% of the chronic zone. For a diffuser at a depth of 605 feet, the corresponding mixing zones are 805 feet and 80.5 feet. Ecology may specify a smaller mixing zone size, however there is no indication at this time that such modification would be expected.

1.3   Purpose and General Approach

The purpose of this assessment is three-fold:

1. to update the simulation of mixing zone dilutions utilizing the more refined diffuser characteristics developed in the predesign process.

2. to provide a more comprehensive assessment of diffuser performance by incorporating additional flow and ambient conditions.

3. to provide a statistical analysis of the diffuser performance.

To accomplish these purposes, this assessment analyzes the initial dilutions calculated under a range of effluent flow rates, ambient density profiles, and current speeds. The results are assessed to confirm that the proposed diffusers meet the appropriate regulatory guidelines and design targets established by King County. These include a (chronic) guideline of 100:1 minimum dilution, drawing from elements contained in the detailed assessments described in Ecology (1998). This assessment also provides documentation of the dilutions at the acute and chronic mixing zones used in assessing compliance with water quality criteria (Ecology 2001). Details of this assessment are provided in a separate report, *Effluent Quality Evaluation for the Brightwater Membrane Bioreactor and Advanced Primary System* (King County, 2003c). This assessment also evaluates the vertical submergence of the plume below the water's surface in relation to a target of maintaining the plume below commercial shellfish beds under the conditions specified by Washington Department of Health.

The general approach involves two steps. The first is to estimate the dilution and plume submergence for each permutation of ambient conditions and expected effluent flow rates. The second step is to combine the expected likelihood of occurrence of the ambient conditions and the effluent flow rate for each simulation to compute the overall probability of occurrence.

The computational approach for the first step is to use the UM3 module of EPA's Visual Plumes Model (Frick et al., 2001) to estimate dilutions at the edge of the acute and chronic mixing zones, and the NRFIELD module to calculate minimum (centerline) initial dilutions and submergence when a plume has reached its trapping level. The NRFIELD module is an updated version of the RSB module of EPA PLUMES Version 3 (EPA, 1994). This computational approach is utilized for varying effluent discharges, ambient stratification conditions, and ambient current speeds for each diffuser alternative. Effluent flow rates were varied in 2-mgd increments throughout the range of potential effluent flow conditions. Ambient conditions were modeled for every density profile obtained at King County's Point Wells #2 station (42 profiles), and at current speeds representing the 10th, 30th, 50th, 70th and 90th percentile speeds observed at the location nearest to each diffuser. In all, 48720 cases are simulated; 24360 in each zone. Initial dilutions are reported at the acute and chronic compliance distances and the plume submergence is reported at the end of the nearfield mixing region.

A statistical representation of the predicted plume characteristics was developed by combining the expected frequency of occurrence of the effluent flow rate and ambient conditions in each calendar month. These values were combined to estimate the likelihood of occurrence for each event.

1.4   Report Format

This report presents predicted initial dilutions and submergence for a range of discharge and receiving water conditions. The report is divided into five sections and one appendix. Section 1 presents the background, purpose, and general approach. Section 2 presents the parameters and the values used in the model studies. Section 3 presents the model results and provides analyses. Section 4 discusses the results and conclusions. Section 5 lists references. Appendix A presents tables of the initial dilution results for each alternative corresponding to various probabilities of occurrence. Appendix B presents salinity and temperature data used to construct the density profiles used in this modeling effort.

2.0.   MODEL PARAMETERS

This section presents the parameters used in the initial dilution modeling. The initial dilution of an effluent discharged to receiving water depends upon three factors: 1) effluent characteristics; 2) diffuser configuration; and 3) ambient receiving water conditions. Table 1 lists the initial dilution parameters for each initial dilution simulation.

Table 1.
Initial Dilution Parameters

Category	Parameter
Effluent	Flow rate
	Temperature
Diffuser	Location and depth
	Length
	Number of ports
	Port diameter
	Orientation
Ambient Water Column	Density stratification
	Current speed
	Current direction

2.1   Effluent Parameters

The effluent discharged to the receiving waters is characterized by flow rate and temperature. The salinity of the effluent is assumed to be zero. The effluent quality of the South Treatment Plant in Renton was used as a template for this modeling. The characteristic effluent temperature from that plant is $65^{o}F$ ($18^{o}C$), which is approximately the annual average. The Brightwater effluent characteristics are expected to be very similar to these, with an annual average temperature of $16\,^{o}C$ and no salinity. A sensitivity analysis, performed in the Phase 2 screen-level assessment (King County 2001), determined that the minimum initial dilution and rise height varied by less that one percent when the temperature varied by $5^{o}F$ ($2.8^{o}C$). Thus, any difference in effluent temperature between the South Treatment Plant and the proposed Brightwater plant is not anticipated to significantly impact dilution.

The Brightwater treatment system is proposed to have an initial capacity of 36 mgd AWWF (Average Wet Weather Flow, 130 mgd peak) and be expanded to 54 mgd AWWF (170 mgd peak) around 2040. A sub-alternative would include combining flows from the existing Edmonds and Lynnwood treatment plants with a Brightwater facility at Unocal at the time of expansion, resulting in an estimated 72 mgd AWWF capacity and a 235 mgd peak flow. Table 2 summarizes these flow rates and the projected plant flows at start-up in 2010. To estimate the distribution of flow events, the existing King County sewer model was used to simulate flow under the existing 2002 land use and a 51-year

history of rainfall events from Seattle-Tacoma International Airport. The model simulation provided a continuous record (hydrograph) of the predicted flow rate to the proposed treatment plant at 10-minute intervals. This hydrograph was scaled to the future design conditions with scaling factors based on the anticipated AWWF (B. Crawford, pers. comm.). This hydrograph captured both inter- and intra- day flow variations, including events beyond the design 20-year storm and utilized the conservative assumption that no storage was used in the treatment plant or influent conveyance lines. The hydrograph indicates flows can occur that exceed the peak design flows, corresponding to the 20-year basis of the design flow and the 51-year extent of the hydrograph. In these events, inline storage or other flow management strategies may be employed. For the purposes of these simulations, the peak flow was not capped at the design flow and dilutions were evaluated at all flows contained within the hydrograph.

The probability distribution associated with this hydrograph for a 54 mgd AWWF plant is illustrated in Figure 3. In addition to assessing the effluent at the plant capacities of 36, 54, and 72 mgd, the predicted plant flow in 2010, 23 mgd AWWF, was also modeled.

Dilution predictions were computed for the range of flows between 8 mgd and 238 mgd, at 2 mgd intervals. This allowed the plume characteristics corresponding to each interval to be associated with the likelihood of occurrence obtained from the hydrograph. An interval of 2 mgd was believed to be a sufficiently fine discretization to accurately capture the plume characteristics throughout the entire range of potential flows.

Table 2.
Effluent Flows

Brightwater Capacity (AWWF)	Average Dry Weather Flow (mgd)	Average Wet Weather Flow (mgd)	Maximum Monthly Flow (mgd)	Peak design flow (mgd)
startup (36 mgd)	18	23		
36 mgd	30	36	45	130
54 mgd	44	54	68	170
72 mgd*	59	72	90	235

Notes: ADWF – Average dry weather flow; AWWF – Average wet weather flow

* The 72 mgd capacity option would not discharge to Zone 7S

2.2 Diffuser Parameters

Location, depth, length, number of ports, port diameter and orientation characterize a diffuser. Details of the diffuser configuration can be found in the *Diffuser Predesign Technical Memorandum* (King County, 2003b). Figure 4 shows the diffuser locations (zones) and the alignment of the proposed outfalls and diffusers within each zone. In each zone, the depths were developed from a marine survey conducted in 2003 (*Marine Survey Report*, King County, 2003d). Table 3 lists the diffuser depths in each zone evaluated in this assessment, as well as the distances to the acute and chronic mixing zones. The chronic distance is 200 feet plus the water depth, and the acute distance is ten percent of the chronic distance.

Table 3.
Regulatory Mixing Zones

Zone	Depth feet (meters)	Distance to chronic compliance feet (meters)	Distance to acute compliance feet (meters)
6	605 (184)	805 (245)	80.5 (24.5)
7 S	605 (184)	805 (245)	80.5 (24.5)

Previous analysis of the plume characteristics considered diffuser lengths between 250 and 750 feet in length. Based on these results, a multi-port diffuser of 500 feet in length was selected in the *Diffuser Predesign* memo (King County, 2003b), and evaluated in this study. Parametrix (2002) developed conceptual diffuser designs for the potential outfall sites. The conceptual designs were used to define the diffuser characteristics (length, numbers of ports, port diameters, etc.) modeled in this study. Each multi-port diffuser was assumed to have 168 ports and each port was assumed to be 4 inches (10 cm) in diameter. The diffuser orientation was taken from the alignments developed as part of the predesign work (*Project Description – Marine Outfall*, King County, 2003a), and are given in Table 4 as the degree deviation of the diffuser axis from true North (positive clockwise).

Table 4.
Diffuser Configurations

Parameter	Zone 6	Zone 7S
Length	500 feet (152 m)	500 feet (152 m)
Number of ports	168	168
Port Spacing	3 feet (91 cm)	3 feet (91 cm)
Port diameter	4 inches (10 cm)	4 inches (10 cm)
Orientation[a]	-77.4	-92.4

[a] Diffuser axis in degrees from true North

2.3   Ambient Water Conditions

Ambient water conditions are expressed in terms of current speeds and density profiles.

2.3.1   Current Speeds

Puget Sound is a dynamic environment, characterized by semi-diurnal tides flowing through deep basins separated by shallower sills. King County undertook an extensive oceanography program to detail the current structure within the area surrounding potential outfall locations. This included the deployment of current meters at 56 locations, which typically recorded current speed and direction at hourly intervals over a one to three month period. Figure 4 shows both the locations of the proposed diffuser alternatives and the nearby current meter stations. Additional details of the oceanography in this region can be found in *Final Report, Puget Sound Physical Oceanography* (King County, 2002b).

The outfall alternative proposed for Zone 6 is less than 500 feet from the current meter deployed at mooring 51, where an RDI 150kHz Workhorse ADCP was deployed between November 29, 2001 and January 8, 2002 at a depth of 183 m. Current speed and direction was recorded at hourly intervals and at 2 meter intervals vertically throughout the water column. Data from this meter was used in modeling the Zone 6 alternative.

The outfall alternative proposed for Zone 7S is less than 1500 feet from the current meter deployed at mooring 23, where an RDI 75kHz NarrowBand ADCP was deployed between January 25, 2001 and March 19, 2001 at a depth of 201 m. Current speed and direction was recorded at hourly intervals and at 2-meter intervals. Data from this meter was used in modeling the Zone 7S alternative.

To summarize the current speed and direction measurements, the distribution of current speeds and directions at three depths (-50m, -100m and –150m) are shown in Figures 5 and 6. Table 5 presents summary statistics of the currents at these three depths.

Five ambient velocity profiles were selected to represent the 10th, 30th, 50th, 70th, and 90th percentile currents at a depth of 150 meters. Variations in direction and vertical distribution of current speed were neglected.

Table 5.
Current Speeds at Mooring 23 and 51

Mooring, Depth (meters)	10th Percentile Current Speed (cm/s)	50th Percentile Current Speed (cm/s)	90th Percentile Current Speed (cm/s)
Mooring 23, 50m	5	17	35
Mooring 23, 100m	5	16	29
Mooring 23, 150m	4	14	29
Mooring 51, 50m	5	14	28
Mooring 51, 100m	4	12	24
Mooring 51, 150m	4	12	24

2.3.2   Density Profiles

The stratification, or density gradient, in the water column affects the effluent plume rise height. The effluent plume is expected to reach a greater height in the water column when the ambient stratification is low, while trapping at deeper depths during periods of high stratification. Density profiles have been measured in the area by a number of agencies, including King County DNR as part of the MOSS study, the Washington State Department of Ecology as part of its ambient monitoring program, and the University of Washington School of Oceanography. The stations monitored by the Department of Ecology, at Admiralty Inlet South (ADM003) and West Point (PSB003), are relatively distant (~8 miles) from the proposed diffuser locations. King County has a long term station off Point Jefferson (KSBP01) and expanded its data collection in 1999 and 2000 to include a series of typically monthly data collection stations across Puget Sound (Figure 4). The Point Wells #2 station is about 0.5 mile north-west of the proposed

diffuser alignment and less than 2 miles south of the proposed diffuser in Zone 6. The University of Washington collects density profiles in this area for classes and projects, as well as on twice-yearly PRISM cruises. The PRISM cruises were initiated in 1998 and typically occur in June and December of each subsequent year. The nearest station to the proposed diffuser alternatives is PRISM station #27, which is approximately 2 miles west of Zone 6 and 3 miles north-west of Zone 7S.

The nearest CTD station to diffuser sites at both Zone 6 and 7S is the King County Point Wells #2 station, where data was collected on approximately monthly intervals between December 1998 and July 2001. Data collection resumed in January 2002 at a new station, Z7SSBW, approximately 0.5 miles south of the Point Wells #2 station. For the purpose of this analysis, the horizontal separation of the two stations was neglected. Figure 7 illustrates the record of observed density profiles with the density (sigma-t units) at three depths, 25m, 75m and 150m. The majority of the CTD profiles extend to depths of 165-175m at this station. A depth of 150 meters was reached on all but one profile (May 2001), where the observations at 147.5m were taken as representative of properties at 150m.

Figure 7(b) illustrates the difference in density, per meter, between 150m, typical of the diffuser depth, and depths of 25 and 75 meters. These depths are presented to provide general characterizations of the stratification in the bottom half of the water column, and the entire water column, excluding any fresh surface layer.

For comparison, the previous Phase 3 plume modeling report selected density profiles from the Point Wells #2 CTD station, representative of a strong summer stratification and a weak winter stratification. The profile of February 13, 2001, which was used for minimum stratification conditions and the profile from July 15, 1999, which was used for maximum stratification conditions. Table 6 shows the measured salinity and temperature profiles for these dates. The temperature and salinity at the deepest measured location in the CTD casts was used to extrapolate beyond the cast depth. The temperature and salinity profiles of all the CTD casts used in this analysis is included in Appendix B.

Table 6.
Winter and Summer Density Profiles

Depth	February 13, 2001		July 15, 1999	
(m)	Salinity o/oo	Temperature °C	Salinity o/oo	Temperature °C
0	30.09	8.19	28.01	13.44
10	30.18	8.19	28.18	12.75
25	30.20	8.20	28.96	11.25
50	30.25	8.25	29.21	10.75
75	30.29	8.24	29.53	10.41
100	30.30	8.19	29.58	10.34
125	30.31	8.15	29.66	10.12
150	30.33	8.12	29.78	10.00
175	30.35	8.09	29.81	9.98
200	30.35	8.09	29.81	9.98

3.0.   ANALYSIS AND RESULTS

The Visual Plumes (Version 1.0) modeling package (Frick et al., 2001) and the UM3 and RSB/NRFIELD models were used for the dilution analysis. UM3 was run to estimate dilutions at the acute and chronic compliance distances. RSB/NRFIELD was run to calculate initial dilutions and submergence for each case at the ZID. As the distances to the estimated chronic compliance zone often exceed the distances to the edge of the nearfield mixing region, the Brooks' intermediate-field model was also run, with default parameters, to calculate additional transport and mixing due to ambient receiving water processes.   The model documentation recommends both the RSB/NRFIELD and UM3 algorithms for discharges of a buoyant fluid into stratified or non-stratified marine waters. The following assumptions were used for this evaluation of potential diffuser zones:

- The UM3 model was used to define dilutions at edges of the acute and chronic mixing zones.

- RSB was used to model the submergence and dilution after nearfield mixing was complete. The results reported by RSB were assumed to define the ZID.

A total of 48,720 cases were modeled: 2 diffuser sites, 1 diffuser length, 116 plant discharges, 42 ambient stratification conditions and 5 ambient current speeds. A summary of the results is tabulated in Appendix A.

To estimate the probability distribution of dilution and submergence, the 42 density profiles were separated by calendar month and each profile in a month was assigned an equal probability of occurrence, and each calendar month was given an equal probability. This was necessary to avoid biasing certain periods of the year due as a result of relatively fewer density profiles than at other times of the year. The five ambient velocity profiles, represent the 10th, 30th, 50th, 70th, and 90th percentile currents, were assigned equal probability of occurrence. Each dilution prediction was assigned a probability based on these estimates of occurrence and the probability of the effluent flow rate, obtained from the 51-year modeled hydrograph.

3.1   Initial Dilution

The dilution results were plotted several ways to examine the range of initial dilutions resulting from the range of discharges. Figures 8 and 9 present the range of predicted dilutions and the minimum initial dilutions at the chronic mixing zone. Figures 10 and 11 illustrate the corresponding acute dilutions for Zone 6 and 7S. While the data points in these figures run together because of the large number of simulations performed for each diffuser zone, the figures show the overall range of results. The minimum dilutions occur during very high plant flows, while the maximum dilutions occur during the lowest modeled plant flows and weak ambient stratification.

The minimum dilutions predicted at the acute and chronic compliance distances are summarized in Table 7 for several system design flow rates. Combined with the predicted distribution of effluent flow rates, the expected probability distribution of

plume dilution is calculated. Table 8 lists the predicted acute and chronic dilutions for several occurrence rates at each of the diffuser zones and several design flows. To illustrate this, Figures 12 and 13 show the cumulative probability of various dilution ratios occurring.

Table 7.
Initial Dilutions at the Acute and Chronic Mixing Zone boundaries for Various Effluent Flow Rates

Outfall Alternative	Flow Rate (mgd)	Acute			Chronic		
		minimum	median	maximum	minimum	Median	maximum
Zone 6	18	390	552	919	440	1501	4802
Zone 6	22	353	490	829	398	1272	4133
Zone 6	30	309	406	708	360	1031	3380
Zone 6	36	284	363	695	346	923	3042
Zone 6	44	255	330	535	301	829	2667
Zone 6	54	230	308	500	255	736	2378
Zone 6	59	221	296	456	242	698	2249
Zone 6	72	201	280	409	222	615	2057
Zone 6	130	113	130	337	158	415	1247
Zone 6	170	81	88	297	146	363	986
Zone 6	235	52	58	253	119	301	652
Zone 7S	18	377	586	950	444	1821	5942
Zone 7S	22	339	489	848	407	1554	4685
Zone 7S	30	291	413	703	357	1197	3633
Zone 7S	36	266	383	625	323	1047	3214
Zone 7S	44	240	366	562	280	878	2772
Zone 7S	54	219	366	515	246	753	2307
Zone 7S	130	99	215	387	178	405	1004
Zone 7S	170	81	188	375	165	340	790

One of the performance criteria for acceptable diffuser performance (also discussed in Ecology's 1998 "Orange Book", Criteria for Sewage Works Design Publication #98-37WQ) is that the diffuser should achieve a minimum initial dilution of 100:1. The minimum dilutions reported in Table 8 show that the proposed diffusers in both zones meet this criterion at the edge of the chronic mixing zone. The minimum dilutions generally occurred for the lowest ambient current speed and larger plant discharges when the water column was strongly stratified.

Table 8.
Minimum Acute and Chronic Initial Dilutions for Various Probabilities of Occurrence and Hydrographs

Mixing Zone		Zone 6 (Unocal)				Zone 7S (Pt Wells)		
	Probability	23 mgd AWWF	36 mgd AWWF	54 mgd AWWF	72 mgd AWWF	23 mgd AWWF	36 mgd AWWF	54 mgd AWWF
Acute	Minimum	201	131	81	54	206	110	81
Acute	1 hr/20 yrs	217	144	90	60	229	178	95
Acute	1 hr/5 yrs	226	151	96	64	257	192	101
Acute	1 hr/year	243	164	105	71	266	222	119
Acute	1 hr/day	406	313	235	186	364	304	261
Acute	50%	499	391	318	276	491	404	371
Chronic	Minimum	235	193	149	131	234	196	171
Chronic	1 hr/20 yrs	266	205	166	147	252	205	178
Chronic	1 hr/5 yrs	310	242	192	164	300	231	198
Chronic	1 hr/year	359	281	227	194	352	274	224
Chronic	1 hr/day	535	420	337	291	521	396	331
Chronic	50%	1388	1015	764	630	1548	1103	807

3.2　Plume Submergence

The NRFIELD (RSB) model was used to predict the upper and lower extents of the plume, once it reached its equilibrium trapping depth.   At each effluent flow rate, the extent of the effluent plume was evaluated for all ambient density profiles and current speeds. The probability of the effluent plume trapping at a given depth was estimated from the fraction of simulation cases that predicted the plume to be trapped at that depth. To avoid biasing from the unequal distribution of density profiles, each simulation in a calendar month was assigned equal probability, as was each calendar month. These results are shown graphically in Figures 14 and 15, as a function of effluent flow rate. These figures illustrate the thickness of the effluent plume after reaching the trapping depth, with a central region that were the plume is most likely to trap, and the decreasing likelihood as the vertical distance increases away from this central region. In general the plume is trapped at deep depths, 80 to 160 meters below the surface, and extends 20 to 60 meters through the water column. Comparison between these two figures shows very little difference between Zone 6 and 7S.

The expected probability of the vertical extent of the plume was computed by combining these results with the hydrograph of effluent flow rates. These results are shown graphically in Figure 16 for both Zone 6 and 7S. The lower graph contains the same results as the upper graph, but is shown with a logarithmic probability scale to enhance the ability to discern the occurrence of low probability events. A probability of 10^{-4}

(0.0001) suggests an occurrence, on average, of 1 hour per year. These results are summarized further in Tables 10 and 11. Table 10 contains the plume submergence expected for various probabilities of occurrence, while Table 11 gives the percent of time the effluent plume is likely to be closer to the surface than various depths. These results show that the effluent plume will generally be trapped at depths greater than 30 meters below the surface 98.8 to 100 percent of the time.

The minimum plume submergence generally occurred for low ambient current speed (4-5 cm/s) and larger plant discharges, when the water column was weakly stratified.

Table 9.
Vertical Plume Submergence for Various Effluent Flow Rates

Outfall Alternative	Flow Rate (mgd)	Submergence (m)		
		minimum	Median	Maximum
Zone 6	18	73	121	154
Zone 6	22	68	117	152
Zone 6	30	59	110	147
Zone 6	36	54	105	144
Zone 6	44	48	101	140
Zone 6	54	40	95	136
Zone 6	59	37	92	134
Zone 6	72	30	86	132
Zone 6	130	7	71	116
Zone 6	170	4	63	101
Zone 6	235	0	50	89
Zone 7S	18	74	123	155
Zone 7S	22	68	119	153
Zone 7S	30	59	111	150
Zone 7S	36	54	108	147
Zone 7S	44	48	104	143
Zone 7S	54	40	97	140
Zone 7S	130	7	71	124
Zone 7S	170	4	65	110

Table 10.
Minimum Plume Submergence for Various Probabilities of Occurrence and Hydrographs

Probability	Zone 6 (Unocal)				Zone 7S (Pt Wells)		
	23 mgd AWWF	36 mgd AWWF	54 mgd AWWF	72 mgd AWWF	23 mgd AWWF	36 mgd AWWF	54 mgd AWWF
Minimum	32	10	2	1	32	10	2
1 hr/20 yrs	34	12	3	1	34	13	3
1 hr/5 yrs	37	17	5	1	38	18	5
1 hr/year	43	27	9	4	45	29	9
1 hr/day	77	69	59	48	80	70	61
50%	116	105	95	87	118	108	98

Table 11.
Percent of Time Effluent Plume Submergence Rises Above Various
Depths for Different Hydrographs

Plume Submergence (meters)	Zone 6 (Unocal)				Zone 7S (Pt Wells)		
	23 mgd AWWF	36 mgd AWWF	54 mgd AWWF	72 mgd AWWF	23 mgd AWWF	36 mgd AWWF	54 mgd AWWF
2	0	0	0	0.0030	0	0	0
10	0	0	0.014	0.055	0	0	0.012
20	0	0.0037	0.038	0.15	0	0.0031	0.033
30	0	0.015	0.091	1.2	0	0.012	0.077
50	0.027	0.43	2.9	4.4	0.021	0.34	2.3
100	20	36	59	74	17	32	54

4.0. CONCLUSIONS

From the results of the initial dilution modeling, the following conclusions can be drawn:

1. The lowest dilution ratios are relatively infrequent events. Both outfall zones achieve a minimum initial dilution of 100:1 at the edge of the estimated zone for chronic compliance. The median dilutions at the edge of the zone for chronic compliance ranged from 630:1 to 1548:1 under the various scenarios modeled. Minimum dilution at the zone for acute compliance ranged from 54:1 to 131:1. In general, lower dilutions were obtained under high flow (peak flows) and slow ambient current conditions. Larger dilutions were obtained under the lowest modeled flow (initial design average wet weather flow) and high ambient current conditions.

2. The effluent plume is predicted to be trapped at depths below -60 meters more than 90 percent of the time. The probability of the plume extending vertically to within 2 meters of the surface is very slight, at less than 0.01%. This probability is greatest for the 72 mgd sub-alternative at the Unocal site, and is reduced for the 54 mgd alternative. Flows from a treatment plant of 36 mgd capacity were always predicted to trap at depths of –10 meters or greater.
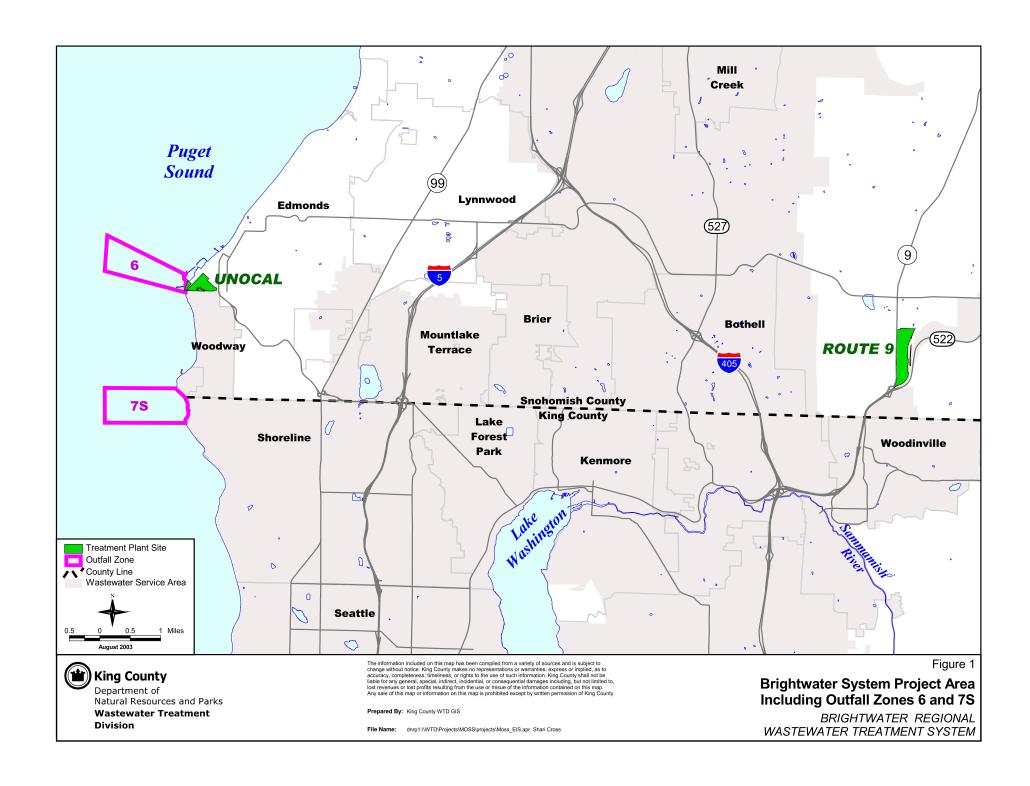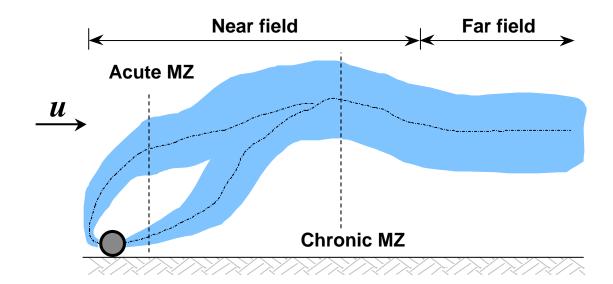
5.0.   REFERENCES

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Washington State Department of Ecology (Ecology), "Criteria for Sewage Works Design," revised December 1998.

6.0.   LIST OF FIGURES

Puget
Sound

**Mill
Creek**

Edmonds

99

Lynnwood

527

9

6

UNOCAL

Brier

Bothell

**Mountlake
Terrace**

5

405

ROUTE 9

522

Woodway

7S

Snohomish County
King County

Shoreline

**Lake
Forest
Park**

Woodinville

Kenmore

*Lake
Washington*

*Sammamish
River*

■ Treatment Plant Site
▭ Outfall Zone
╱ County Line
▨ Wastewater Service Area

N

0.5   0   0.5   1 Miles

August 2003

Seattle

Prepared By: King County WTD GIS

File Name: dnrp1:\\WTD\Projects\MOSS\projects\Moss_EIS.apr Shari Cross
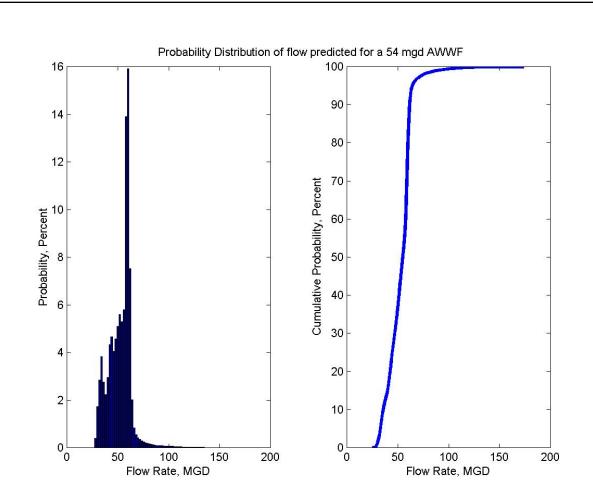
Figure 1

**Brightwater System Project Area
Including Outfall Zones 6 and 7S**

*BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM*

Near field | **Far field**

Acute MZ

u

Chronic MZ

Notes: The location of the near field and far field regions will vary depending on diffuser configuration and ambient conditions. The acute and chronic mixing zones (MZ) depend on the depth of discharge.

Figure 2

Schematic Illustration of a Vertical Cross-section of an Effluent Plume
BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM

File Name: TM095F02.doc
Prepared by: Bruce Nairn

Probability Distribution of flow predicted for a 54 mgd AWWF
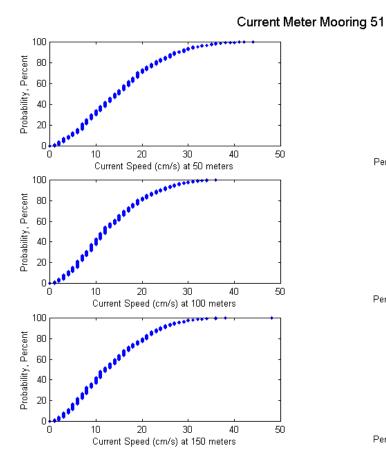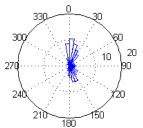
Notes: Based on a 51-year simulation of
treatment plant flows. Right panel illustrates
the cumulative probability distribution.

File Name: TM09XF03.doc
Prepared by: Bruce Nairn

Figure 3
Probability Distribution of Flow (54 mgd AWWF)
BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM

Figure 4
Oceanographic Sampling Locations
BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM

King County
Department of
Natural Resources and Parks
Wastewater Treatment
Division

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Data Sources: King County Datasets

File Name: TM095F02

Legend:
- Prism CTD Stations
- ADCP Current Meter Locations
- Aanderaa Current Meter Locations
- KC CTD Stations
- Preferred outfall alignment
- Outfall Zones

0.2   0   0.2   Miles

Current Meter Mooring 51

Percent Probability of Current Direction at 50 meters

Percent Probability of Current Direction at 100 meters

Percent Probability of Current Direction at 150 meters

Notes: The cumulative distribution of current speed is shown along with the current rose depicting the probability of current direction. Three depths are illustrated, 50m (top), 100m (middle) and 150 (bottom).

File Name: TM095F05.doc
Prepared by: Bruce Nairn

Figure 5
Current Distribution at Mooring 51
BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM
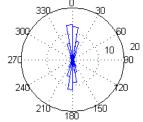
Current Meter Mooring 23
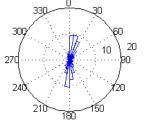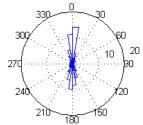

Percent Probability of Current Direction at 50 meters

Percent Probability of Current Direction at 100 meters
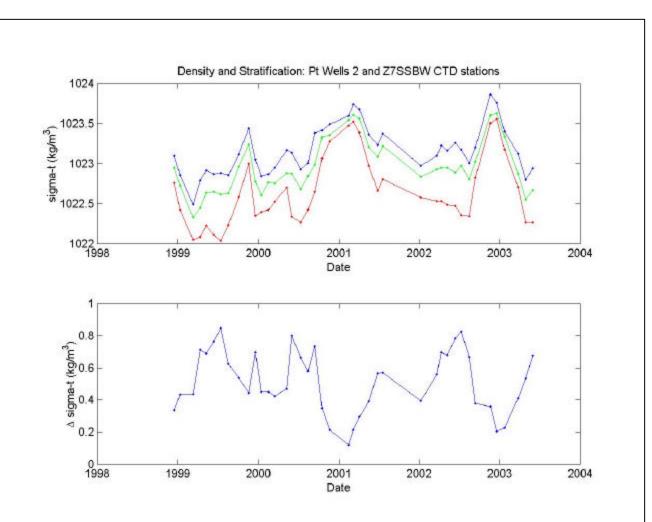
Percent Probability of Current Direction at 150 meters
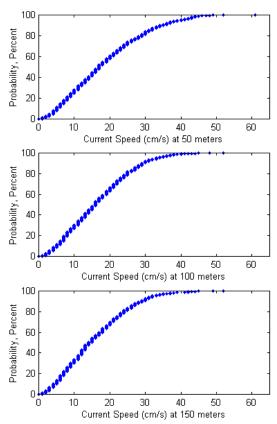
Notes: The cumulative distribution of current speed is shown along with the current rose depicting the probability of current direction. Three depths are illustrated, 50m (top), 100m (middle) and 150 (bottom).
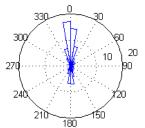
File Name: TM095F06.doc
Prepared by: Bruce Nairn

Figure 6
Current Distribution at Mooring 23
BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM

Density and Stratification: Pt Wells 2 and Z7SSBW CTD stations
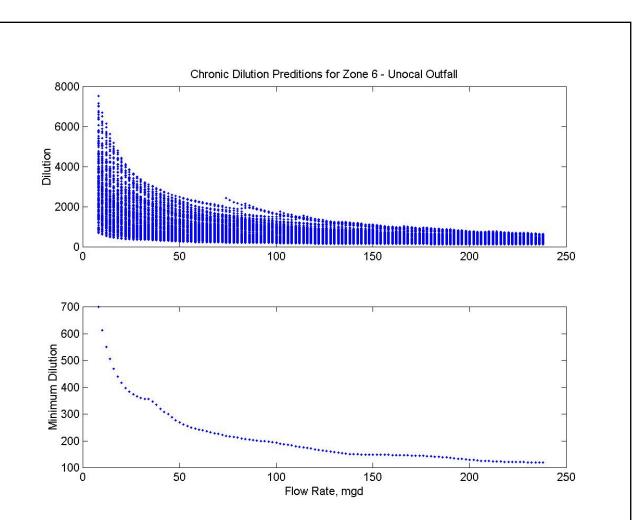
Notes: Time series of density measurements made at the Pt Wells #2 and Z7SSBW CTD stations. Top panel illustrates variations in density (sigma-t) with time. The density at three depths are shown, 25m (red, bottom line), 75m (green, middle line), and 150m (blue, top line). The bottom panel depicts the variation of stratification, calculated from the difference in density at the 25m and 150m levels.

Figure 7
Time Series of Density and Stratification
BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM

Chronic Dilution Preditions for Zone 6 - Unocal Outfall

Notes: Top panel illustrates the dependence of the predicted dilution on the effluent flow rate, evaluated at the edge of the chronic mixing zone for the proposed outfall in Zone 6. The minimum dilution at each flow rate is shown in the bottom panel.

Figure 8
Dilution at the Chronic Mixing Zone, Zone 6
BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM
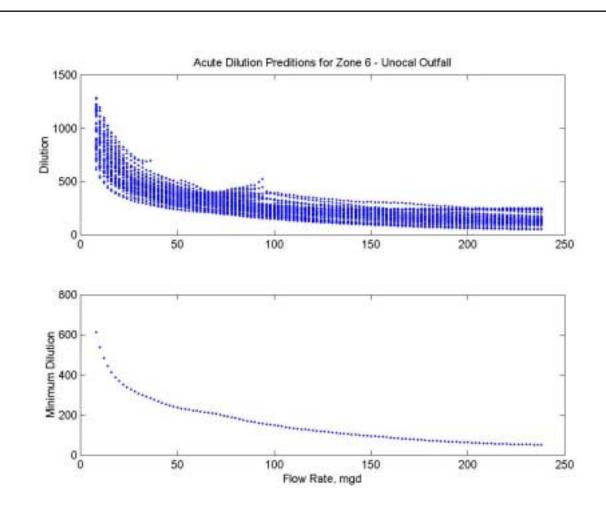
Chronic Dilution Preditions for Zone 7S - Route 9 Outfall

Notes: Top panel illustrates the dependence of the predicted dilution on the effluent flow rate, evaluated at the edge of the chronic mixing zone for the proposed outfall in Zone 7S. The minimum dilution at each flow rate is shown in the bottom panel.

Figure 9

Dilution at the Chronic Mixing Zone, Zone 7S
BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM
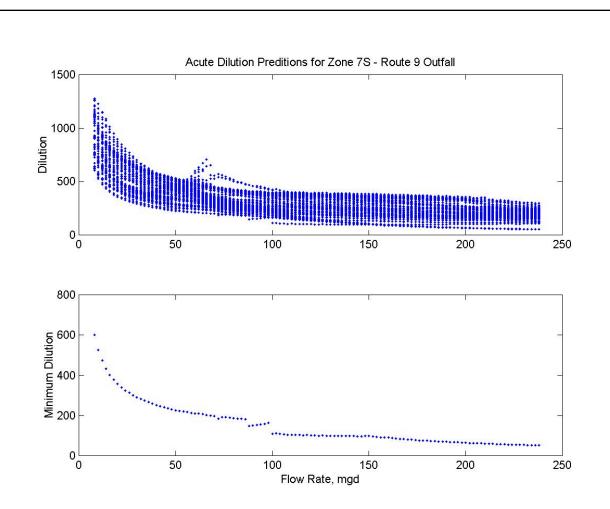
File Name: TM095F09.doc
Prepared by: Bruce Nairn

Acute Dilution Preditions for Zone 6 - Unocal Outfall

Notes: Top panel illustrates the dependence of the predicted dilution on the effluent flow rate, evaluated at the edge of the acute mixing zone for the proposed outfall in Zone 6. The minimum acute dilution at each flow rate is shown in the bottom panel.

Figure 10

Dilution at the Acute Mixing Zone, Zone 6
BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM

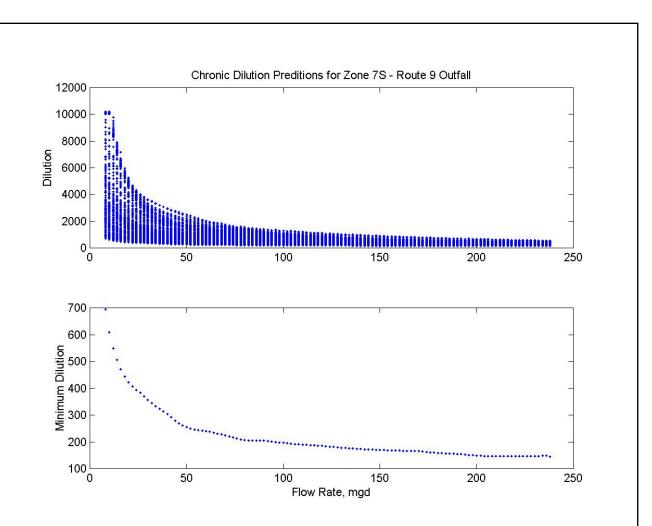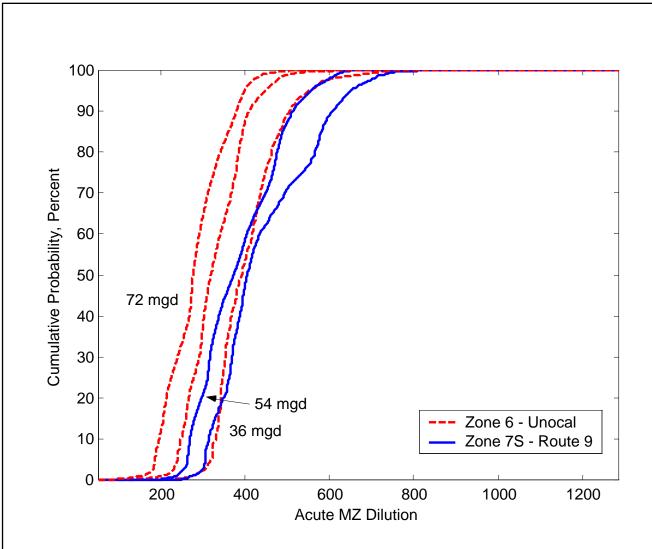Acute Dilution Preditions for Zone 7S - Route 9 Outfall

Notes: Top panel illustrates the dependence of the predicted dilution on the effluent flow rate, evaluated at the edge of the acute mixing zone for the proposed outfall in Zone 6. The minimum acute dilution at each flow rate is shown in the bottom panel.

Figure 11
Dilution at the Acute Mixing Zone, Zone 7S
BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM
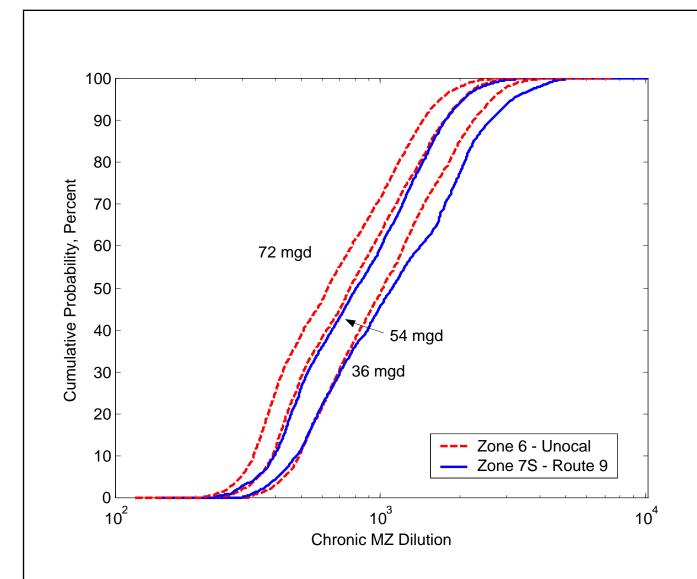
Notes: Cumulative probability distribution of dilution predictions at the acute mixing zone boundary for the proposed alternatives in Zone 6 (dashed) and 7S (solid). Shown are the distributions for an effluent discharge hydrograph corresponding to 36mgd, 54mgd, and 72mgd AWWF.

Figure 12

Probability Distribution of Dilution at the Acute Mixing Zone
BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM

File Name: TM095F12.doc
Prepared by: Bruce Nairn

72 mgd

54 mgd

36 mgd

--- Zone 6 - Unocal
— Zone 7S - Route 9

Cumulative Probability, Percent

Chronic MZ Dilution
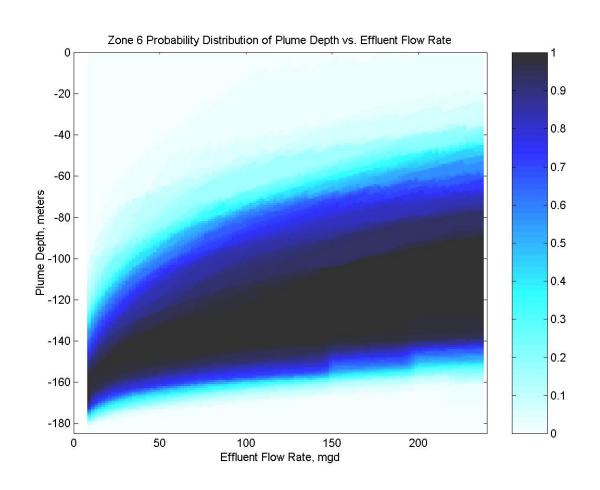
Notes: Cumulative probability distribution of dilution predictions at the chronic mixing zone boundary for the proposed alternatives in Zone 6 (dashed) and 7S (solid). Shown are the distributions for an effluent discharge hydrograph corresponding to 36mgd, 54mgd, and 72mgd AWWF.

Figure 13

Probability Distribution of Dilution at the Chronic Mixing Zone
BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM
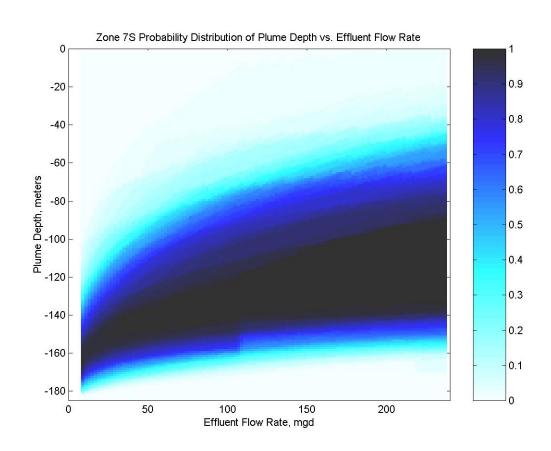
File Name: TM095F13.doc
Prepared by: Bruce Nairn

Zone 6 Probability Distribution of Plume Depth vs. Effluent Flow Rate

Notes: Figure illustrates the probability that a portion of the effluent plume is predicted to be at various depths after the initial dilution and plume rise, as a function of effluent flow rate. The probability of occurrence is expressed as a fraction (1.0 = 100%).
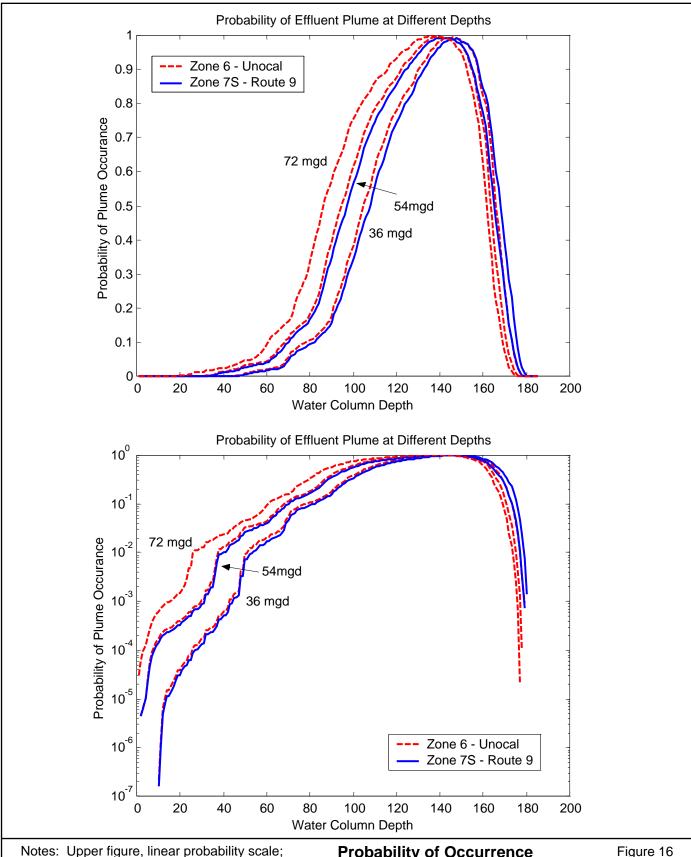
Figure 14

Probability Distribution of Plume Depth, Zone 6
BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM

Zone 7S Probability Distribution of Plume Depth vs. Effluent Flow Rate

Notes: Figure illustrates the probability that a portion of the effluent plume is predicted to be at various depths after the initial dilution and plume rise, as a function of effluent flow rate. The probability of occurrence is expressed as a fraction (1.0 = 100%).

Figure 15

Probability Distribution of Plume Depth, Zone 7S
BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM

Probability of Effluent Plume at Different Depths

Notes: Upper figure, linear probability scale; lower figure, logarithmic probability scale. Indicated flow rates are the AWWF of the hydrograph used in the simulation.

**Probability of Occurrence
of the Effluent Plume at Various Depths**
*BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM*

Figure 16

Appendix A
Initial Dilution Results

Probability	Acute Mixing Zone					Chronic Mixing Zone				
Plant	Unocal			Pt Wells		Unocal			Pt Wells	
Capacity	36 mgd	54 mgd	72 mgd	36 mgd	54 mgd	36 mdg	54 mgd	72 mgd	36 mgd	54 mgd
(minimum)	131	81	54	110	81	201	149	131	196	171
0.01	276.5	205.9	154.6	274.9	238.7	344.2	281.6	243.7	329.3	275.3
0.05	316.9	240	185.6	304.3	262.8	434	347.2	297.7	407.8	341.9
0.1	329.3	244.9	195	314.3	268.7	492.4	390.4	331.8	479.6	395.9
0.2	341.3	265.5	212.3	346.7	295.5	583.9	442.1	376.6	578.7	458.5
0.3	353.2	290.8	239.8	368.5	315.8	692.7	507.8	425.8	699.5	531.8
0.4	367	301.4	267	386.9	337.2	829.6	623.5	510.7	888.3	656.5
0.5	390.9	317.5	275.7	403.8	371.1	1015.3	764.2	629.9	1103.4	806.8
0.6	417.4	341	291	433.2	402.8	1218.8	933.3	775.3	1405.8	1005.9
0.7	435.1	366.1	310.9	492.7	447.2	1455.3	1141.2	957.6	1748.8	1205
0.8	461.5	384.1	340.9	565.1	474.7	1802.6	1403.1	1166.1	2067.8	1435.2
0.9	504.7	407.8	378.1	607.8	512.4	2230.5	1741.4	1440.6	2585.8	1748.8
0.95	550.8	449.1	398	650.1	554.9	2622.3	2023.2	1683	3155.7	2036.4
0.99	675.2	504.7	442.7	733.2	619.4	3310.5	2567	2195.1	4350.8	2689.7

Appendix B
Ambient Profiles

Salinity (psu)

Cast Date	Cast Depth	Depth (meters)									
		0	10	25	50	75	100	125	150	175	200
Dec 17 1998	174	26.9707	29.4275	29.6244	29.7458	29.9077	30.0044	30.0715	30.1956	30.2586	30.2586
Jan 12 1999	162	29.0781	29.0871	29.1089	29.2282	29.3807	29.4331	29.4851	29.5008	29.5192	29.5192
Mar 11 1999	174	27.8097	28.242	28.3784	28.6131	28.7174	28.8092	28.8709	28.9057	29.0847	29.0847
Apr 12 1999	167	28.276	28.3829	28.4346	28.782	28.8963	28.9576	28.9849	29.3355	29.4858	29.4858
May 10 1999	173	28.3109	28.4391	28.7394	29.0067	29.2505	29.3543	29.4422	29.5997	29.8535	29.8535
Jun 14 1999	166	26.7146	27.9297	28.8464	29.1131	29.4055	29.5188	29.6014	29.6773	29.6949	29.6949
Jul 15 1999	167	28.0094	28.1808	28.9628	29.2062	29.5273	29.5864	29.6615	29.7839	29.8124	29.8124
Aug 19 1999	172	27.9755	29.2352	29.3313	29.5342	29.727	29.833	29.8631	29.9431	30.1676	30.1676
Oct 05 1999	166	29.772	29.8062	29.8373	29.9501	30.1729	30.1985	30.2926	30.3291	30.3628	30.3628
Nov 18 1999	176.5	26.5172	29.253	30.0944	30.2705	30.3286	30.3626	30.4157	30.4888	30.5117	30.5123
Dec 20 1999	164.5	25.516	28.048	28.962	29.452	29.553	29.616	29.876	29.984	29.999	29.999
Jan 13 2000	162	27.7204	28.8175	28.9567	29.0358	29.1659	29.407	29.4267	29.4368	29.4428	29.4428
Feb 17 2000	178.5	28.1103	28.7415	28.8398	29.1849	29.2796	29.316	29.3521	29.3957	29.4971	29.4994
Mar 15 2000	177.5	28.3485	28.7687	28.9606	29.1064	29.2477	29.3726	29.4446	29.4877	29.535	29.5464
May 08 2000	177	26.6126	29.0349	29.3882	29.5537	29.6459	29.7153	29.803	29.923	30.0222	30.0257
May 31 2000	174.5	26.2964	28.6969	29.1154	29.403	29.6912	29.778	29.8806	30.0262	30.1166	30.1166
Jul 11 2000	173.00	28.897	29.197	29.295	29.409	29.683	29.774	29.868	29.968	30.08	30.08
Aug 14 2000	165.50	29.542	29.618	29.697	29.781	30.081	30.194	30.235	30.265	30.307	30.307
Sep 12 2000	173.50	29.802	29.807	30.04	30.276	30.33	30.409	30.566	30.719	30.832	30.832
Oct 17 2000	165	30.2238	30.2427	30.4176	30.5246	30.6228	30.6581	30.6814	30.6995	30.7124	30.7124
Nov 21 2000	176.50	30.308	30.379	30.445	30.469	30.514	30.531	30.552	30.584	30.65	30.682
Feb 13 2001	176.00	30.089	30.18	30.196	30.251	30.291	30.3	30.308	30.333	30.352	30.352
Mar 06 2001	163.00	30.006	30.132	30.228	30.296	30.332	30.35	30.394	30.486	30.516	30.516
Apr 03 2001	178.50	28.007	29.885	30.106	30.23	30.312	30.351	30.393	30.47	30.564	30.591
May 15 2001	147.5	28.3919	29.2443	29.7732	29.9728	30.0371	30.1194	30.1353	30.1732	30.1732	30.1732
Jun 25 2001	173.532	29.244	29.313	29.692	29.991	30.131	30.16	30.187	30.268	30.303	30.303
Jul 18 2001	177.00	29.878	29.989	30.07	30.383	30.494	30.561	30.634	30.656	30.697	30.7
Jan 08 2002	173.5	28.488	29.102	29.298	29.51	29.545	29.583	29.713	29.738	29.721	29.721
Mar 21 2002	163	26.995	28.711	28.926	29.283	29.459	29.482	29.563	29.652	29.688	29.688
Apr 10 2002	180	26.256	28.323	29	29.189	29.481	29.561	29.702	29.84	29.982	29.984
May 08 2002	170.5	28.121	28.282	29.031	29.327	29.596	29.727	29.797	29.88	30.003	30.003
Jun 12 2002	173	28.574	28.623	29.246	29.483	29.689	29.944	30.025	30.132	30.199	30.199
Jul 10 2002	178.5	23.192	28.62	29.284	29.593	29.955	30.088	30.146	30.206	30.279	30.29
Aug 15 2002	178	29.419	29.522	29.627	29.8	29.996	30.117	30.157	30.187	30.221	30.252
Sep 11 2002	178	29.304	30.04	30.148	30.285	30.358	30.435	30.49	30.528	30.569	30.602
Nov 18 2002	154	30.135	30.664	30.712	30.758	30.822	30.914	31.014	31.078	31.085	31.085
Dec 17 2002	179.5	29.887	30.514	30.621	30.672	30.704	30.715	30.741	30.82	30.911	30.926
Jan 22 2003	176.5	29.44	29.782	29.951	30.15	30.157	30.19	30.242	30.271	30.385	30.386
Feb 25 2003	178.5	26.8996	29.1699	29.48	29.7246	29.8124	29.8401	29.8527	29.9019	29.9215	29.9327
Mar 25 2003	170	25.356	28.951	29.348	29.509	29.562	29.632	29.778	29.848	29.898	29.898
Apr 28 2003	156	28.494	28.806	28.903	29.154	29.209	29.436	29.47	29.523	29.524	29.524
May 28 2003	166	9.7402	29.053	29.106	29.283	29.483	29.689	29.769	29.844	29.997	29.997

Temperature (degrees Centigrade)

Cast Date	Cast Depth	Depth (meters)									
		0	10	25	50	75	100	125	150	175	200
Dec 17 1998	174	9.5269	9.9328	9.9967	10.0794	10.21	10.3489	10.4596	10.67	10.7755	10.7755
Jan 12 1999	162	9.5967	9.5925	9.5768	9.449	8.9867	8.8486	8.832	8.7341	8.5967	8.5967
Mar 11 1999	174	8.0032	8.22	8.1833	8.1096	8.0979	8.0723	8.0165	8.0108	7.9361	7.9361
Apr 12 1999	167	8.4205	8.3089	8.3003	8.2548	8.2578	8.2609	8.2661	8.272	8.266	8.266
May 10 1999	173	9.5446	9.303	8.9716	8.8954	8.8843	8.8874	8.895	8.8759	8.8179	8.8179
Jun 14 1999	166	12.8011	11.5324	10.2779	9.8372	9.6062	9.5646	9.5466	9.5518	9.5427	9.5427
Jul 15 1999	167	13.4404	12.7547	11.2469	10.7545	10.4056	10.3397	10.1159	9.9954	9.9781	9.9781
Aug 19 1999	172	14.1154	12.1824	11.7768	11.4412	11.2728	11.0272	10.9834	10.9372	10.8342	10.8342
Oct 05 1999	166	12.1631	12.1054	12.0117	11.7753	11.3257	11.2504	11.2015	11.155	11.0308	11.0308
Nov 18 1999	176.5	10.3837	10.7297	10.7634	10.5218	10.408	10.268	10.097	9.941	9.8976	9.8912
Dec 20 1999	164.5	8.9898	9.1117	9.2857	9.3261	9.5275	9.3547	9.8464	9.9501	9.9699	9.9699
Jan 13 2000	162	8.8518	8.9452	8.9788	8.9462	8.6728	8.6539	8.569	8.4873	8.4795	8.4795
Feb 17 2000	178.5	7.8846	8.1244	8.1434	8.1696	8.1339	8.105	8.0636	8.0485	8.0018	8.0011
Mar 15 2000	177.5	7.9944	8.0437	8.0821	8.0753	8.0527	8.0554	8.0332	8.0212	8.0331	8.0394
May 08 2000	177	10.234	9.4814	9.1813	9.3108	9.2947	9.2255	9.0369	8.8473	8.7855	8.785
May 31 2000	174.5	11.8848	10.9044	10.1527	9.6484	9.5627	9.4984	9.5025	9.5905	9.6071	9.6071
Jul 11 2000	173.00	13.119	11.883	11.425	11.134	10.759	10.607	10.737	10.62	10.625	10.625
Aug 14 2000	165.50	14.589	12.738	12.28	12.163	11.589	11.552	11.554	11.519	11.452	11.452
Sep 12 2000	173.50	13.184	13.007	12.489	11.971	11.872	11.768	11.568	11.361	11.219	11.219
Oct 17 2000	165	12.0157	11.9854	11.8205	11.5002	11.2199	11.1305	11.1132	11.0991	11.0978	11.0978
Nov 21 2000	176.50	10.511	10.585	10.719	10.721	10.57	10.394	10.246	10.096	9.8329	9.7587
Feb 13 2001	176.00	8.1942	8.191	8.1962	8.249	8.242	8.1939	8.1534	8.1236	8.0898	8.0895
Mar 06 2001	163.00	8.0786	8.007	8.0134	7.9984	7.9843	7.9763	7.9608	7.9381	7.9277	7.9277
Apr 03 2001	178.50	8.6921	8.4269	8.3296	8.2436	8.2341	8.2537	8.2539	8.2829	8.3031	8.3101
May 15 2001	147.5	10.5542	10.2215	9.3599	9.1018	9.2047	9.1715	8.9555	8.8579	8.8579	8.8579
Jun 25 2001	173.532	12.379	11.823	10.889	10.64	10.408	10.342	10.218	10.184	10.144	10.144
Jul 18 2001	177.00	13.858	12.193	11.767	11.187	11.274	11.271	11.203	11.124	11.101	11.102
Jan 08 2002	173.5	9.6034	9.4121	9.5282	9.2543	9.0728	9.0026	9.2832	9.2145	9.0228	9.0228
Mar 21 2002	163	7.6561	7.7676	7.8107	7.9917	8.0068	8.0333	7.9704	7.8838	7.862	7.862
Apr 10 2002	180	8.793	8.7841	8.2498	8.0786	7.9691	7.9541	7.9769	7.9835	7.9969	7.9992
May 08 2002	170.5	9.1938	9.0719	8.7465	8.6256	8.6224	8.5842	8.5919	8.6538	8.6793	8.6793
Jun 12 2002	173	11.586	10.86	9.9164	9.622	9.4808	9.3858	9.3655	9.3478	9.3441	9.3441
Jul 10 2002	178.5	13.879	11.844	10.854	10.461	10.245	10.26	10.241	10.224	10.201	10.196
Aug 15 2002	178	15.141	13.167	12.437	11.599	11.456	11.257	11.182	11.149	11.165	11.195
Sep 11 2002	178	12.685	12.296	11.997	11.816	11.787	11.662	11.587	11.552	11.526	11.497
Nov 18 2002	154	10.638	10.638	10.598	10.53	10.55	10.433	10.27	10.169	10.158	10.158
Dec 17 2002	179.5	9.9206	9.864	9.8666	9.8801	9.8261	9.7893	9.7205	9.5712	9.4263	9.405
Jan 22 2003	176.5	8.7808	8.8603	8.9524	8.9531	8.9599	8.9796	9.0664	9.1166	9.3466	9.3477
Feb 25 2003	178.5	8.4028	8.8675	8.9841	8.9956	8.8663	8.838	8.8179	8.8424	8.8195	8.8069
Mar 25 2003	170	9.0721	8.9507	8.9219	8.9099	8.9194	8.8895	8.8311	8.7882	8.7636	8.7636
Apr 28 2003	156	9.8653	9.6784	9.5673	9.3014	9.2605	9.2017	9.1932	9.245	9.2317	9.2317
May 28 2003	166	13.603	10.855	10.544	10.016	9.8722	9.9649	9.9641	9.9339	9.8797	9.8797